



Sensing and Awareness in Microsystems

Dr. John Kitching

Physicist,
National Institute of Standards
and Technology

The views and opinions presented by the invited speakers are their own
and should not be interpreted as representing the official views of DARPA or DoD

Approved For Public Release, Distribution Unlimited

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE MAR 2009		2. REPORT TYPE		3. DATES COVERED 00-00-2009 to 00-00-2009	
4. TITLE AND SUBTITLE Chip-Scale Atomic Devices. Precision Instruments based on Lasers, Atoms and MEMS				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Institute of Standards and Technology, Time and Frequency Division, 325 Broadway, Boulder, CO, 80305-3328				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES MTO (DARPA Microsystems Technology Office) Symposium, 2009, Mar 2-5, San Jose, CA					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 13	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Chip-Scale Atomic Devices

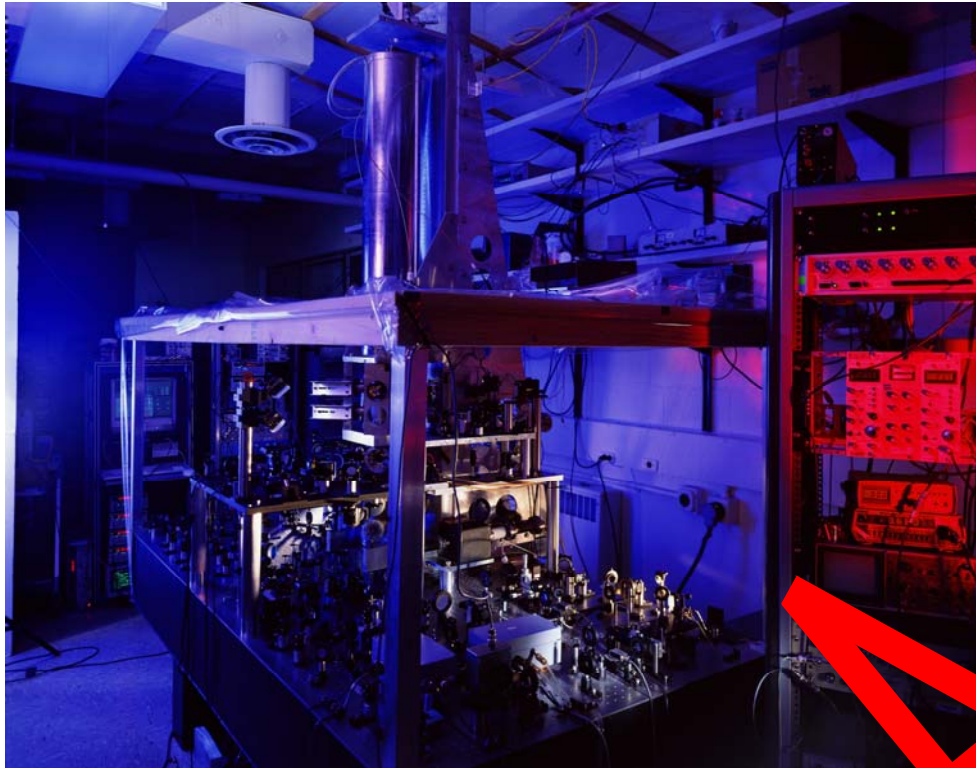
**Precision Instruments based on
Lasers, Atoms and MEMS**

John Kitching

**Time and Frequency Division
NIST**

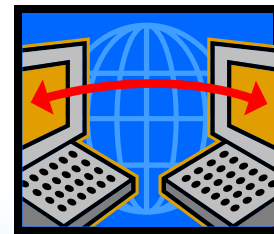
**Microsystems Technology Symposium
San Jose, CA, March, 2009**

Atomic Clocks

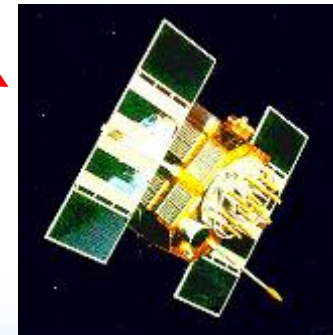


NIST F-1 Primary Atomic Frequency Standard

- Time: most accurately measured physical quantity
- NIST: most accurate clock in the world
 - Frequency uncertainty $\sim 4 \times 10^{-16}$
 - Timing instability < 1 ns over 1 week



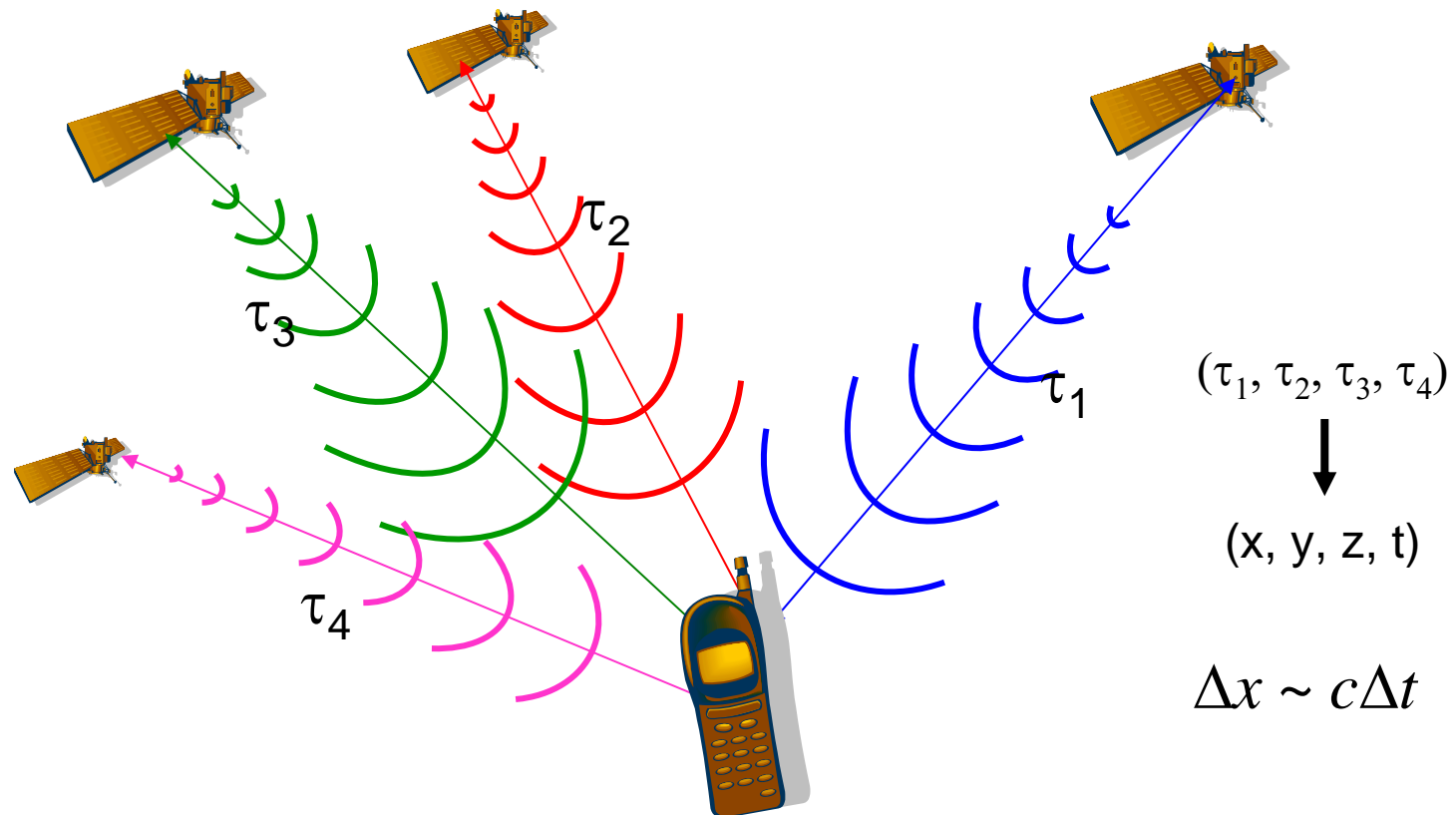
Telecom Sync



GPS System

Precision is a Big Deal

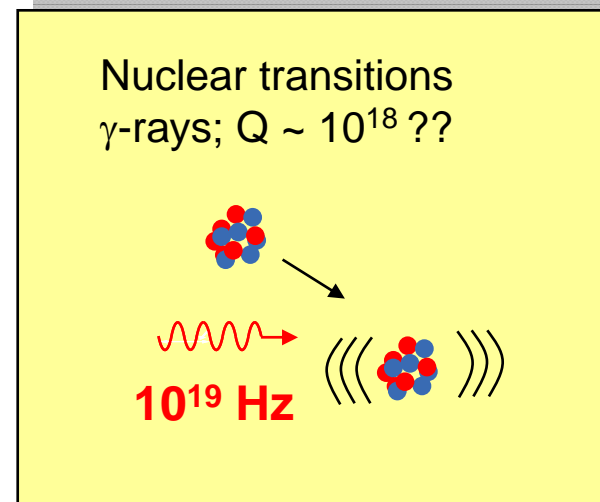
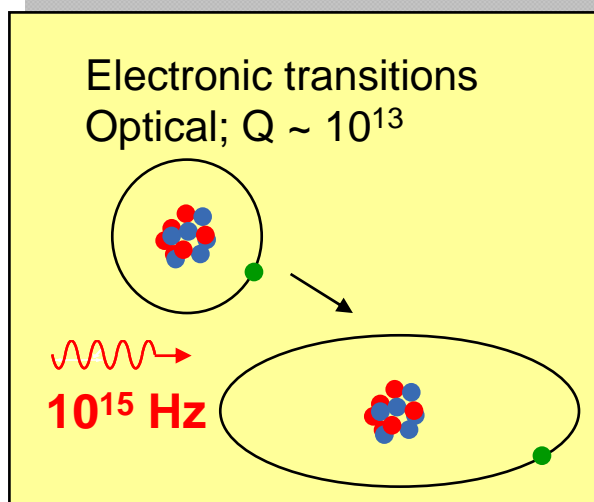
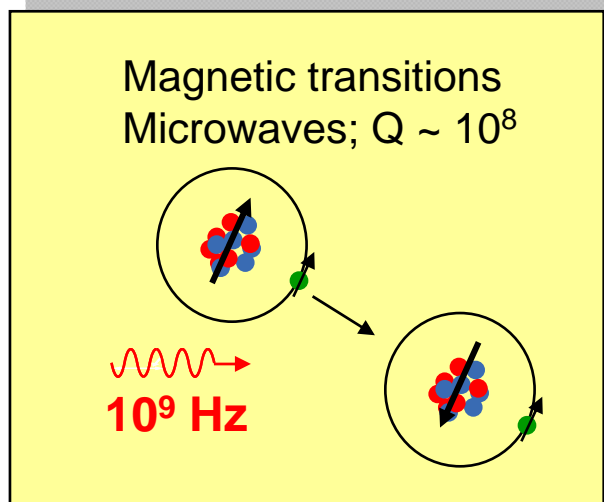
- Speed of light: 30 cm/ns



- Positioning to 1 m \Rightarrow ns timing required
- Positioning to 1 mm \Rightarrow ps timing

Origin of the Precision?

- High frequencies, long coherence times

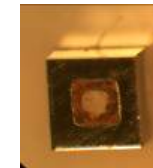
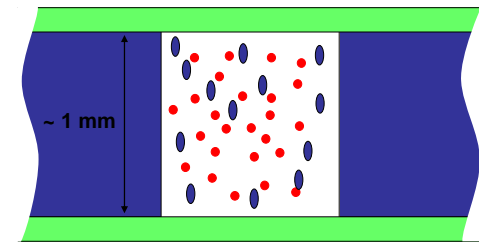
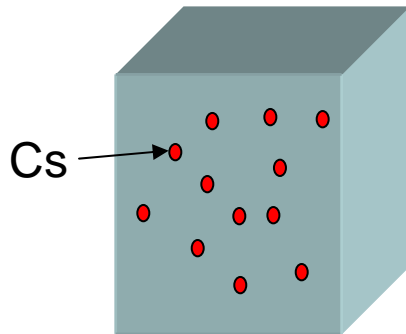


- High signal-to-noise
 - Spectroscopic measurements and/or large numbers of atoms
 - As high as 10^7 @ 1 sec
- Insensitive to environment

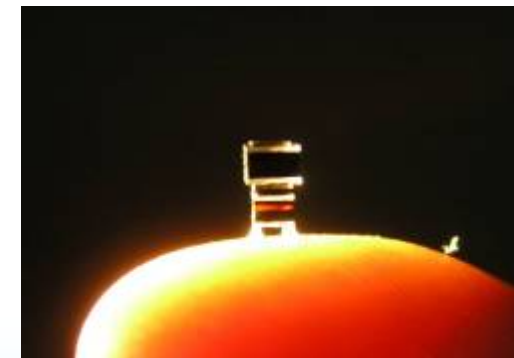
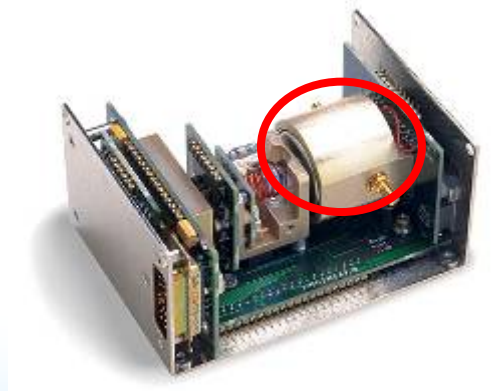
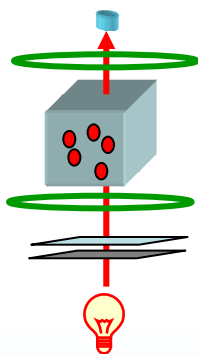


MEMS Fabrication

- Alkali atom vapor cells



- Atomic clock physics packages

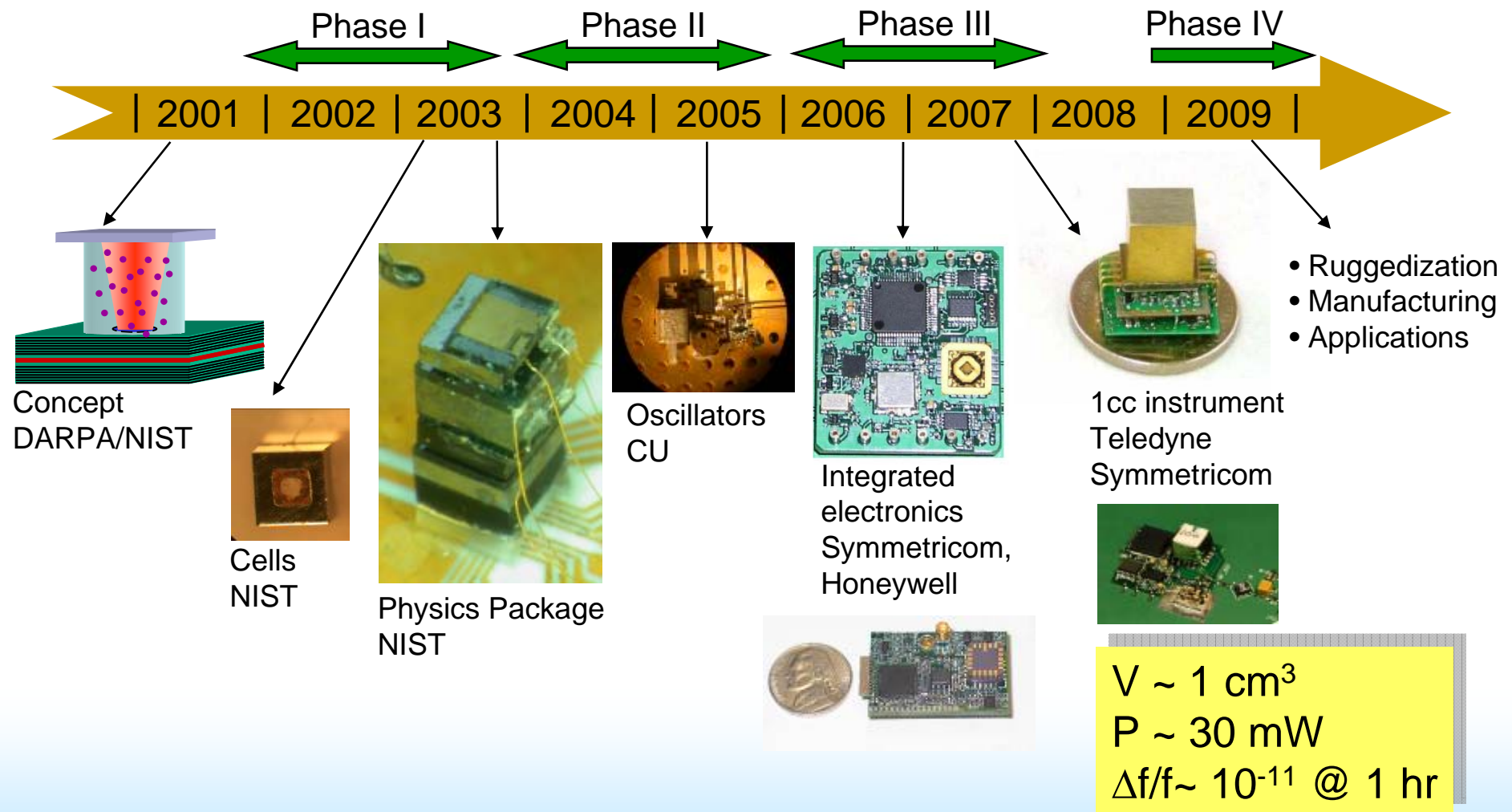




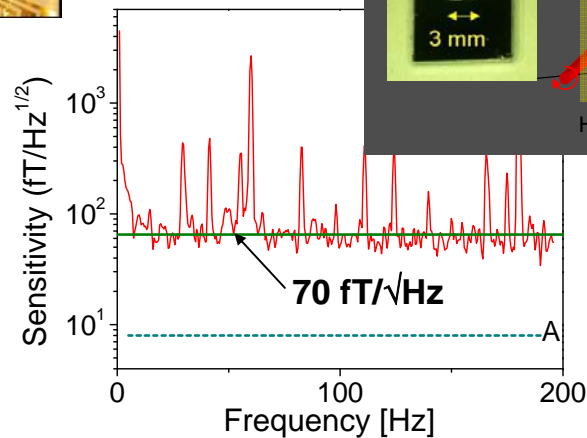
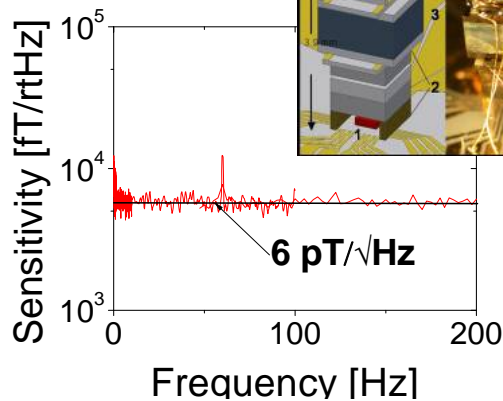
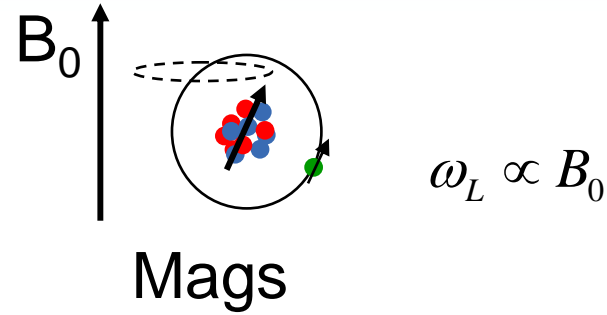
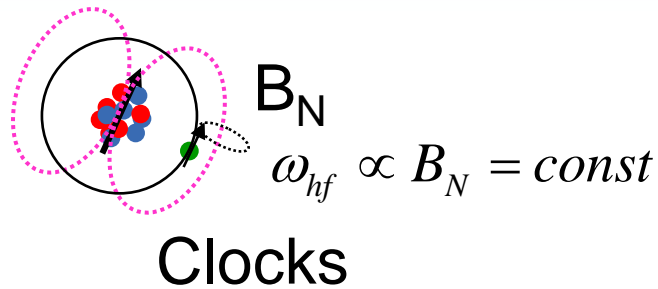
CSAC Program



Guided by: Bill Tang ... Clark Nguyen ... Amit Lal ...

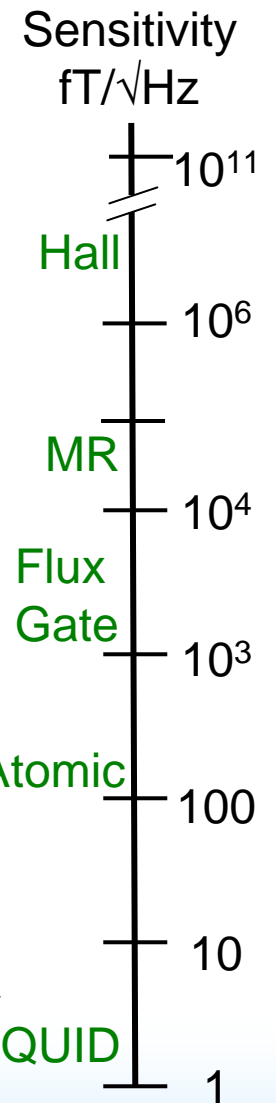


Beyond CSAC: Magnetometers



SQUID sensitivity

~~Cryogenics~~

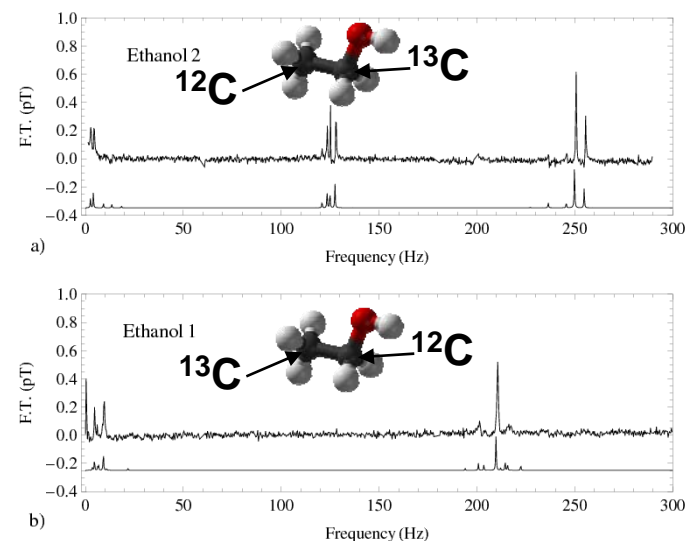
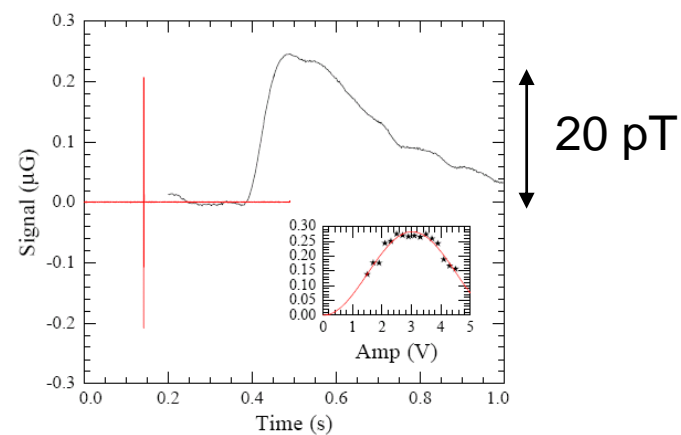


Microfluidic NMR



With A. Pines, D. Budker, UC-Berkeley

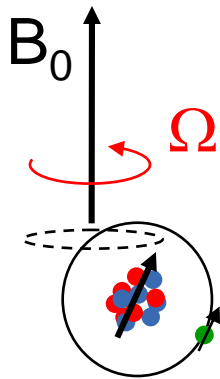
M. Ledbetter, et al., PNAS, **105**, 2286, 2008



NMR at zero field: simple spectra, compact apparatus

Approved For Public Release, Distribution Unlimited

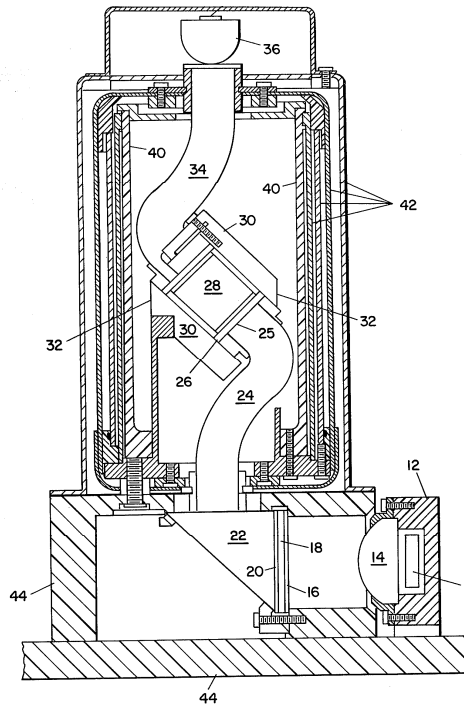
Beyond CSAC: Gyroscopes



$$\omega_L = \gamma B_0 + \Omega$$

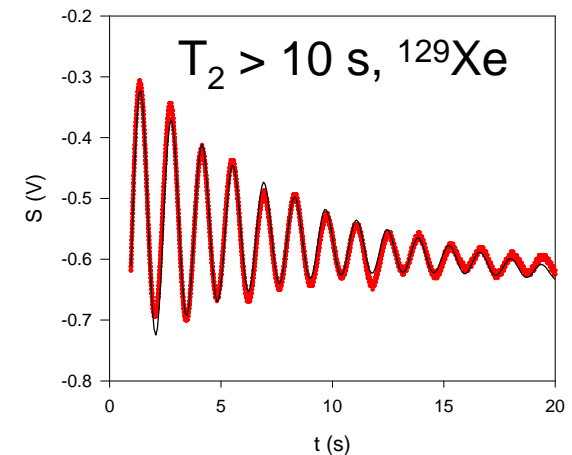
Nuclear spins

- Longer coherence time
- Lower field sensitivity
- ^{129}Xe , ^{21}Ne , ^{199}Hg ...
- Read out precession with alkali magnetometer



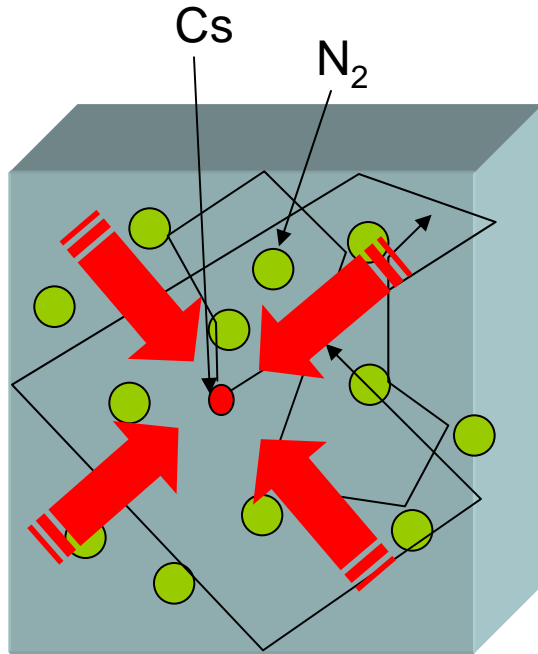
Litton, 1979
1000 cm³, 0.1 °/hr

+ MEMS

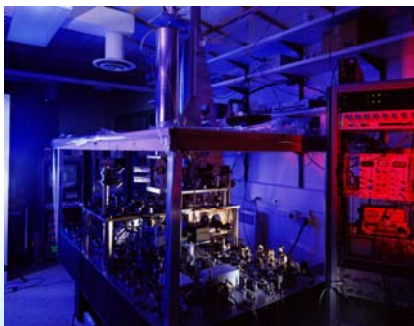


NGIMG:
1 cm³, 5 mW, Nav-grade

Laser-Cooled Atoms



$V_{at} \sim 500 \text{ m/s} \rightarrow 1 \text{ cm/s}$
 $\sim 1 \mu\text{s/cm} \rightarrow T_c \sim 1 \text{ s}$



- Wall coatings
- Buffer gases
- Laser cooling


Nobel Prize (1997)
 C. Cohen-Tannoudji,
 W. D. Phillips, S. Chu

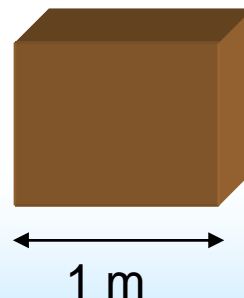
Fountain clocks
 Atom interferometers

- Gyros
- Gravimeters, accelerometers
- Magnetometers

Bose-Einstein condensates

$\Delta t/t \sim 10^{-16}$
 $\Delta\Omega/\Delta t \sim 10^{-6} \text{ }^\circ/\text{hr}$
 $\Delta x/\Delta t \sim 5 \text{ m/h}$
 $\delta B/dx \sim 10 \text{ fT}/\sqrt{\text{Hz/mm}}$

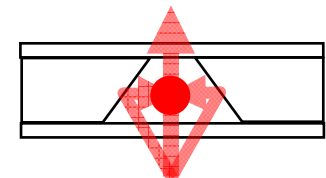

 gBECi
 PINS
 (DSO)



w/ MTO ?

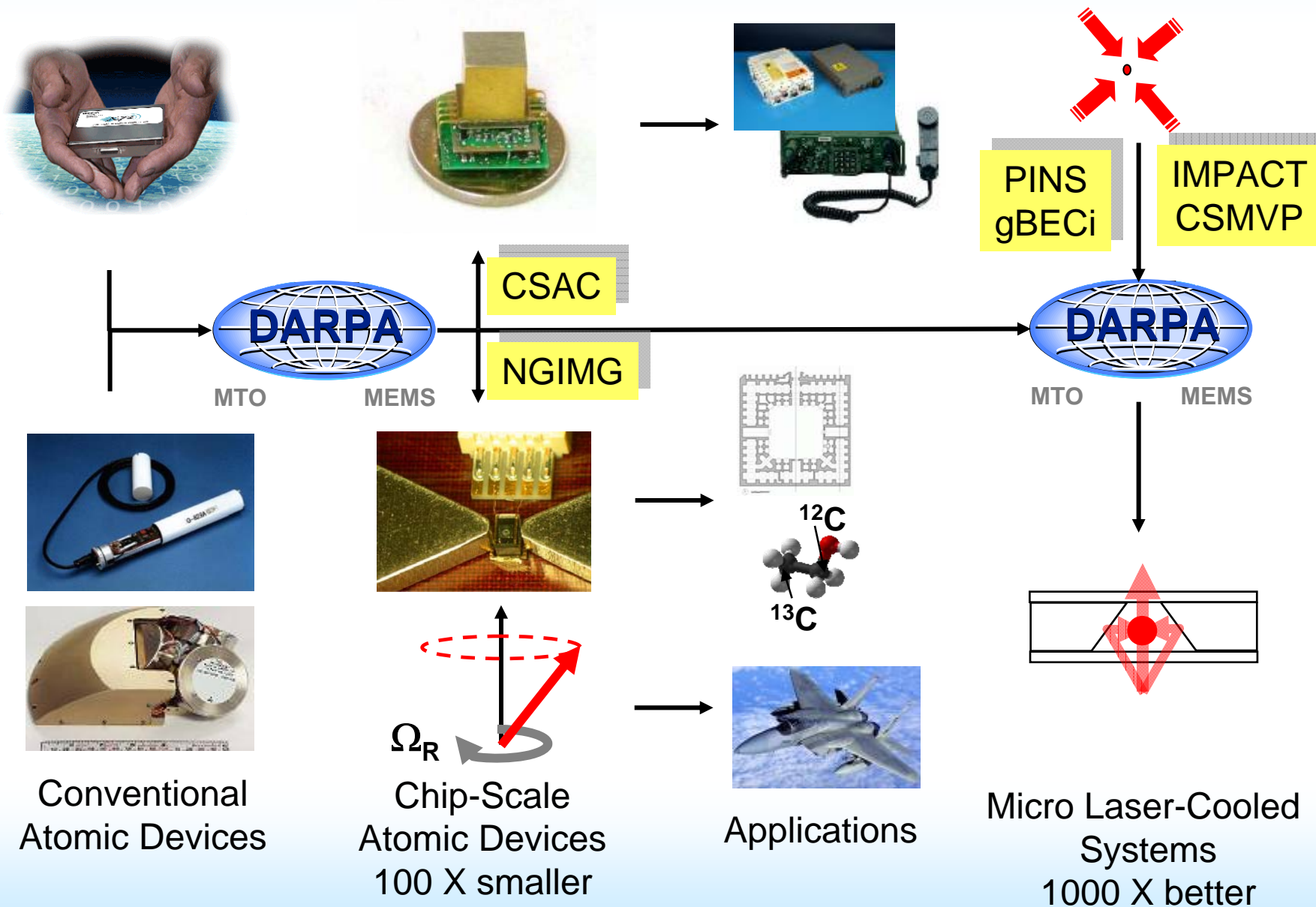


IMPACT, CSVMP



1 cm ?
 5 mW ?

Chip-Scale Atomic Devices: 2001-2009



MICROSYSTEMS TECHNOLOGY OFFICE

MTO SYMPOSIUM

The logo for the Microsystems Technology Office (MTO) Symposium. It features the letters 'MTO' in a large, bold, metallic font. The 'O' is a circle containing a globe with the word 'DARPA' on it. Circuit traces extend from the 'M' and 'O'. Below 'MTO' is the word 'SYMPOSIUM' in a smaller, white, sans-serif font. The entire logo is set against a dark background with a reflection effect below it.

BUILDING THE FUTURE
FROM THE INSIDE OUT

The background of the poster is a collage of various technological and infrastructure elements. On the left, there's a large satellite dish and a solar panel array. In the center, a ship's mast with various antennas and sensors is visible. On the right, there's a large, complex structure that looks like a space station or a large industrial facility. The entire background is in shades of blue and white, with a grid pattern overlaid.

Approved For Public Release, Distribution Unlimited